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RESEARCH MEMORANDUM

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A FUEL-DISTRIBUTION CONTROL FOR GAS-TURBINE ENGINES

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NATIONAL ADVISORY COMMITTEE
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WASHINGTON
June 14, 1948

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RESEARCH MEMORANDUM

A FUEL-DISTRIBUTION CONTROL FOR GAS-TURBINE ENGINES

By Harold Gold and David M. Straight

SUMMARY

The principle of operation of a device to control the distribution of fuel to any number of discharge nozzles of a gas-turbine engine is presented. A description of an experimental model of the device and the results of a bench investigation are presented. This device controlled the flow to four discharge nozzles within 2 percent of perfect distribution over a wide range of fuel flow and was unaffected by uneven discharge-nozzle pressures.

INTRODUCTION

In current gas-turbine engines the fuel is pumped into a manifold from which it flows to the various atomizing nozzles. If the fuel manifold is large and symmetrical, the effect of fluid friction is negligible and fuel reaches all the discharge nozzles at the same static pressure. If all the nozzles have the same area and equal coefficients at all flows, the flow through the discharge nozzles will at all times be equal. The complexity imposed on the nozzle by the need for a well-atomized discharge, however, makes the equalizing of fuel flow through the nozzles over a wide range of fuel flows extremely difficult. With the relatively low pressures used in some current gas-turbine-engine fuel manifolds at low flows, differences in nozzle elevations and inertia forces markedly affect the fuel distribution. In addition, the malfunctioning of one nozzle can greatly disturb the fuel flow to the other nozzles. By means of the distribution-control method described, these effects can be entirely overcome.

In the course of investigation at the NACA Cleveland laboratory of methods to obtain uniform fuel sprays in gas-turbine engines, a fuel-distribution control was developed that presents a possible means for obtaining improved and more consistent fuel distribution in gas-turbine engines than can be obtained with the use of the manifold system. The principle of operation of the fuel-distribution control, a description of the experimental model used in the investigation, and the results of the bench investigation are presented.

PRINCIPLE OF OPERATION

Control method. - If matched metering jets were placed upstream of the discharge nozzles in each branch of a fuel manifold, the static pressure of the fuel on the upstream side of the jets would be equal in each branch, but the downstream static pressure would be affected by the discharge nozzle and the fuel distribution would not be improved. If, however, automatic valves were placed between the metering jets and the discharge nozzles to maintain equal static pressures on the downstream side of the metering jets in each branch, the distribution would be controlled by the metering jets and would be unaffected by the discharge nozzles. Such a system, schematically shown in figure 1, is the basis of the fuel-distribution control developed during this investigation.

Control mechanism. - A schematic diagram of the fuel-distribution control is presented in figure 2. Fuel is delivered to this control under pressure from a pressure-type metering control (not shown). The fuel flows through the inlet and fills the manifold passage. From the manifold passage the fuel flows into the individual manifold branches and through the branch metering jets and the downstream pressure-regulating valves to the individual branch discharge nozzles. Fuel also flows from the manifold passage into the pilot branch, through the pilot metering jet and the pilot regulator jet, to the pilot discharge nozzle.

By means of the pressure-equalizing passage, the static pressures in the individual chambers A are maintained equal. The control diaphragms that separate chambers A and B position the downstream pressure-regulating valves until the pressures in chambers B are equal to the pressures in chambers A.

If the branch discharge-nozzle pressures are equal to the pilot discharge-nozzle pressure, the static-pressure drop across each of the downstream pressure-regulating valves will be equal to the static-pressure drop across the pilot regulator jet. The open area of the valves will then be proportional to the area of the pilot regulator jet and this area will remain fixed at all fuel flows. If any one branch discharge-nozzle pressure should rise above the pilot discharge-nozzle pressure, the downstream pressure-regulating valve in the branch supplying that nozzle would have a reduced static-pressure drop and would move to a position of larger opening. If any one branch discharge-nozzle pressure should fall below the pilot discharge-nozzle pressure, the reverse would occur. In either case the static-pressure drop across the branch metering jet remains equal to the drop across the pilot metering jet and the fuel distribution is undisturbed.

The pilot discharge nozzle can supply fuel to the engine in the same manner as the branch discharge nozzles. Because of the dependence of the entire system, however, on the flow in the pilot branch, it may be advisable to return the pilot flow to the fuel tank as indicated in figure 2.

EXPERIMENTAL MODEL, APPARATUS, AND PROCEDURE

Experimental model. - A photograph of the experimental model of the four-branch fuel-distribution control used in the bench investigation is shown in figure 3. The control diaphragms are mounted on four faces of a cube. In operation, the control is so mounted that the control diaphragms are each in a vertical plane, which eliminates the effect of the valve-plug weight on the pressure in chamber B. Other arrangements can be used but the weight of the plugs must always be made to act in the same direction on all the valves. The pilot metering and regulator jets are in a separate housing, which is not shown in figure 3.

Matching of metering jets. - The metering jets used in the experimental model were drilled and then placed in a Navy-type orifice comparator. (See reference 1.) While in the comparator, the four jets were matched by polishing with crocus cloth. After the jets were matched on the comparator, a flow check was made with naphtha. The results of the flow check (fig. 4) show that the four jets, which were matched in the comparator, give nearly the same flows over a wide range of metering heads.

Bench apparatus. - The apparatus used with the experimental model of the fuel-distribution control is schematically shown in figure 5 and photographically shown in figure 6. Total fuel flow to the fuel-distribution control was measured with a rotameter having a range of 200 to 2000 pounds per hour. The fuel flowing in each branch passed through a rotameter having a range of 40 to 200 pounds per hour. Above a total fuel flow of 800 pounds per hour, therefore, only the total-flow rotameter could be used. From the branch rotameters the fuel was discharged through four diaphragm-operated, spring-loaded nozzles. One of the four nozzles was vented to a variable-pressure air line in order that its discharge pressure could be varied. A well-type mercury manometer was used to measure the discharge-nozzle pressure.

The four branch rotameters were calibrated in series after installation on the bench apparatus. The calibration was recorded by plotting the float position of each rotameter in millimeters against the fuel flow in pounds per hour as indicated by one of the four rotameters. The fuel flow through the pilot branch was measured with a rotameter having a range of 3 to 25 pounds per hour.

The pressure drop across each of the metering jets was measured with a 100-inch naphtha manometer. Each chamber B was connected to one tube of a bank of four tubes that was arranged as shown in figure 5. The differences in the level of the fuel in the four tubes indicated the differences in static pressure in the four chambers B and thereby the accuracy with which the downstream pressure-regulating valves were functioning.

The fuel was naphtha having a specific gravity of 0.74 at a temperature of 70° F.

RESULTS AND DISCUSSION

Discharge-nozzle calibration. - The discharge nozzles that were used in the bench runs on the experimental model were first operated on a manifold to determine the ability of the nozzles to distribute the fuel equally. The results of this calibration, which are shown in figure 7, indicate a maximum deviation of 30 percent from perfect distribution.

Performance of experimental model. - The bench performance of the experimental model of the fuel-distribution control is shown in figure 8. In the range of total fuel flow from 180 to 300 pounds per hour, the deviation of any branch flow from perfect distribution was no greater than 2 percent. Above a total fuel flow of 320 pounds per hour, the deviation was less than 1 percent. Although branch-rotameter ranges limited the maximum recorded branch fuel flow, use of the total-flow rotameter alone extended the total-fuel-flow range to the limit of 1260 pounds per hour imposed by the bench apparatus. Comparison of the pressures in chambers B indicated that the same accuracy of control was maintained over this additional range. Comparison of the results shown in figures 7 and 8 clearly indicates the marked improvement that can be obtained with this type of automatic fuel-distribution control.

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In order to demonstrate the ability of the experimental model to compensate for uneven nozzle pressures, the discharge pressure of one of the four nozzles was varied from 3 to 13.8 inches of mercury gage while the three others were kept at an approximately constant pressure of 11.3 inches of mercury gage. The flow through the control was kept constant at 370 pounds per hour. The results of this run, which are given in figure 9, show that the branch fuel flow remained constant within 3 percent over the entire range of nozzle pressures from 3 to 13.3 inches of mercury gage. Above a pressure of 13.3 inches of mercury gage, the downstream pressure-regulating valve in that branch began to lose control. The fuel-distribution control can be made to compensate for a much wider range of uneven nozzle pressures at any pressure level by altering the dimensions of the downstream pressure-regulating valve and the size of the pilot regulator jet.

SUMMARY OF RESULTS

A study of an experimental model of a fuel-distribution control for gas-turbine engines gave the following results:

1. The experimental model controlled the fuel flow to four unmatched discharge nozzles within ± 2 percent of perfect distribution at a total flow of 180 to 1260 pounds per hour.

2. The experimental model maintained the fuel flow through a discharge nozzle within 3 percent of a constant value while the discharge-nozzle pressure was varied from 3 to 13.3 inches of mercury gage.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. Anon.: Instruction Manual D-3217 for Operation of Orifice Comparator - Navy Type Model III, Bureau of Aeronautics. Instruction Manual D-3217, The Meriam Instr. Co. (Cleveland), Jan. 10, 1944.

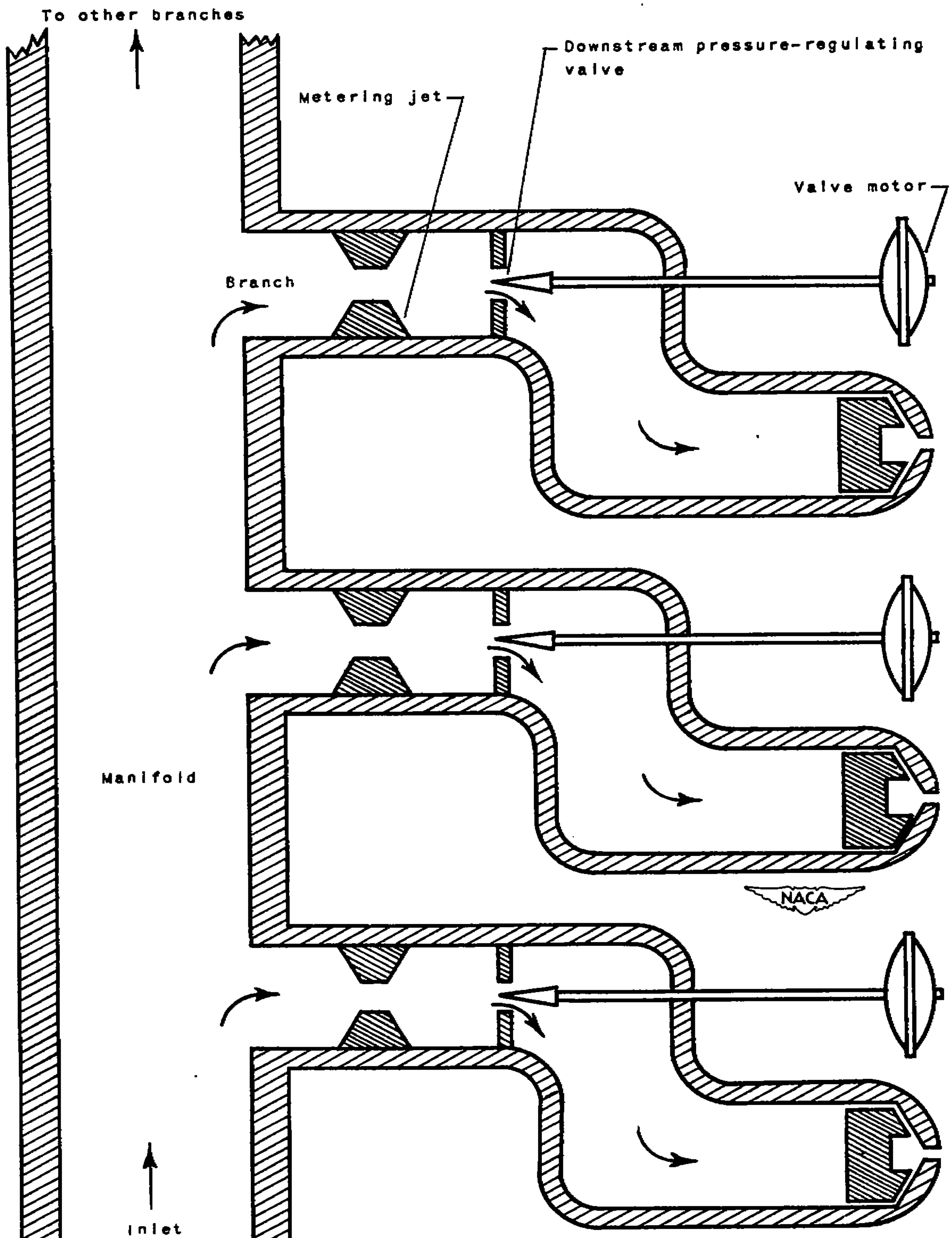

Figure 1. - Schematic diagram of control elements in apparatus for maintaining equal fuel distribution in gas-turbine engines.

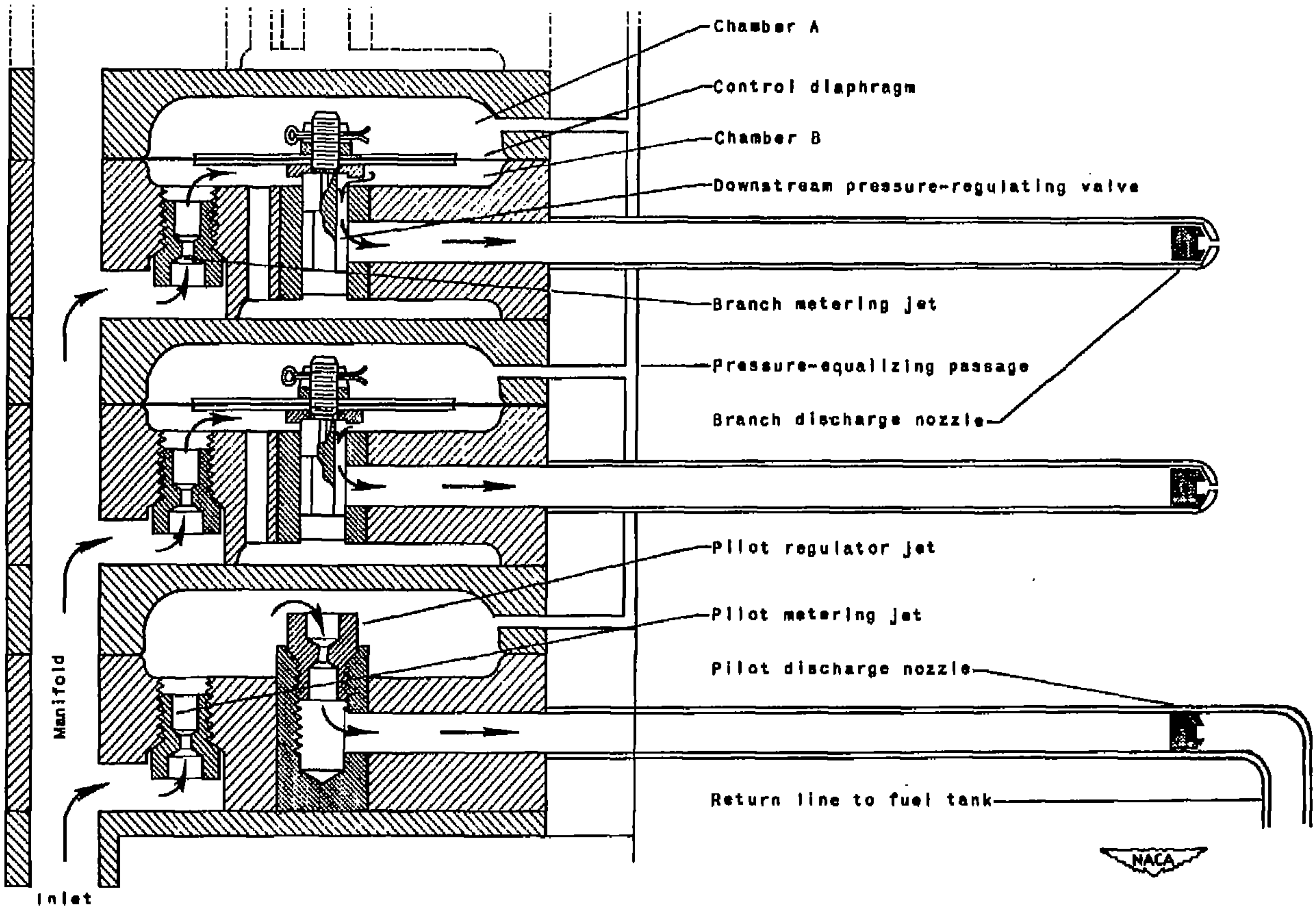

Figure 2. - Schematic diagram of fuel-distribution control for gas-turbine engines.

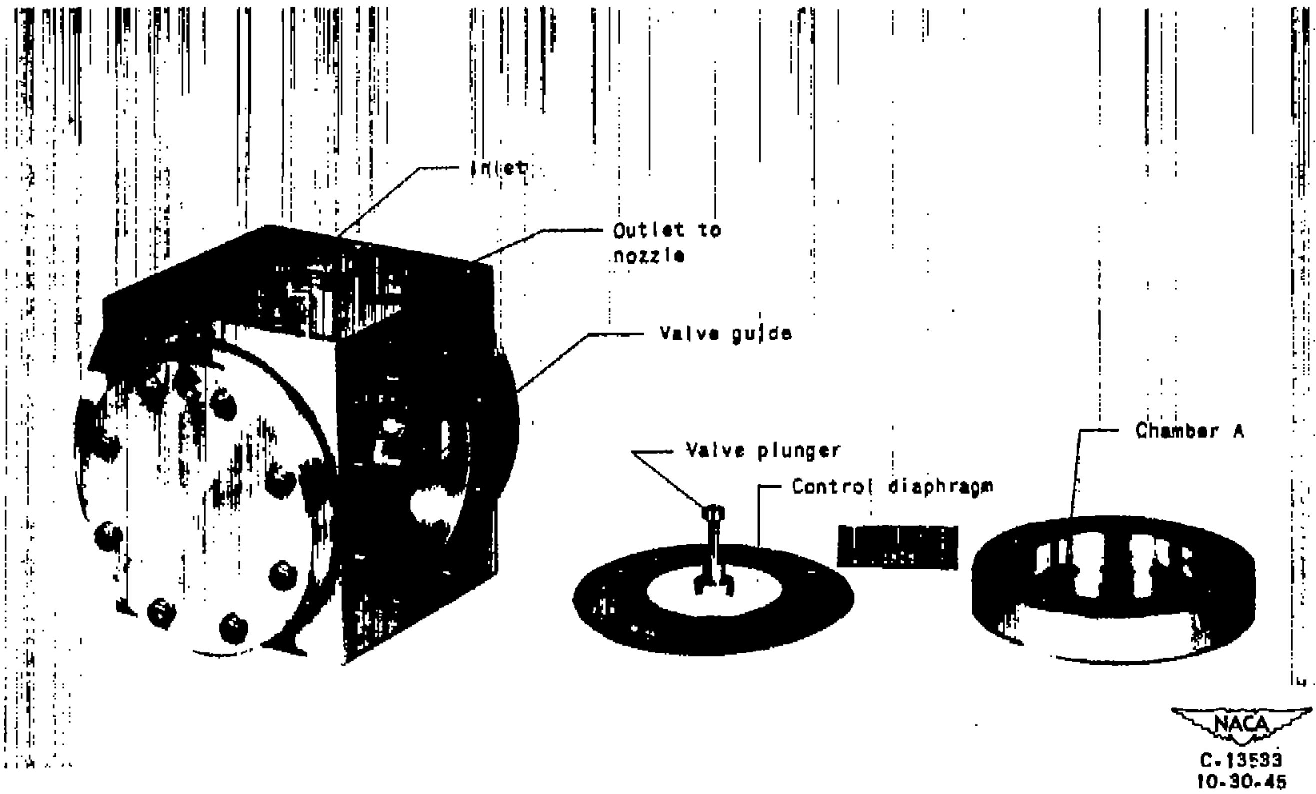

Figure 3. - Experimental model of fuel-distribution control.

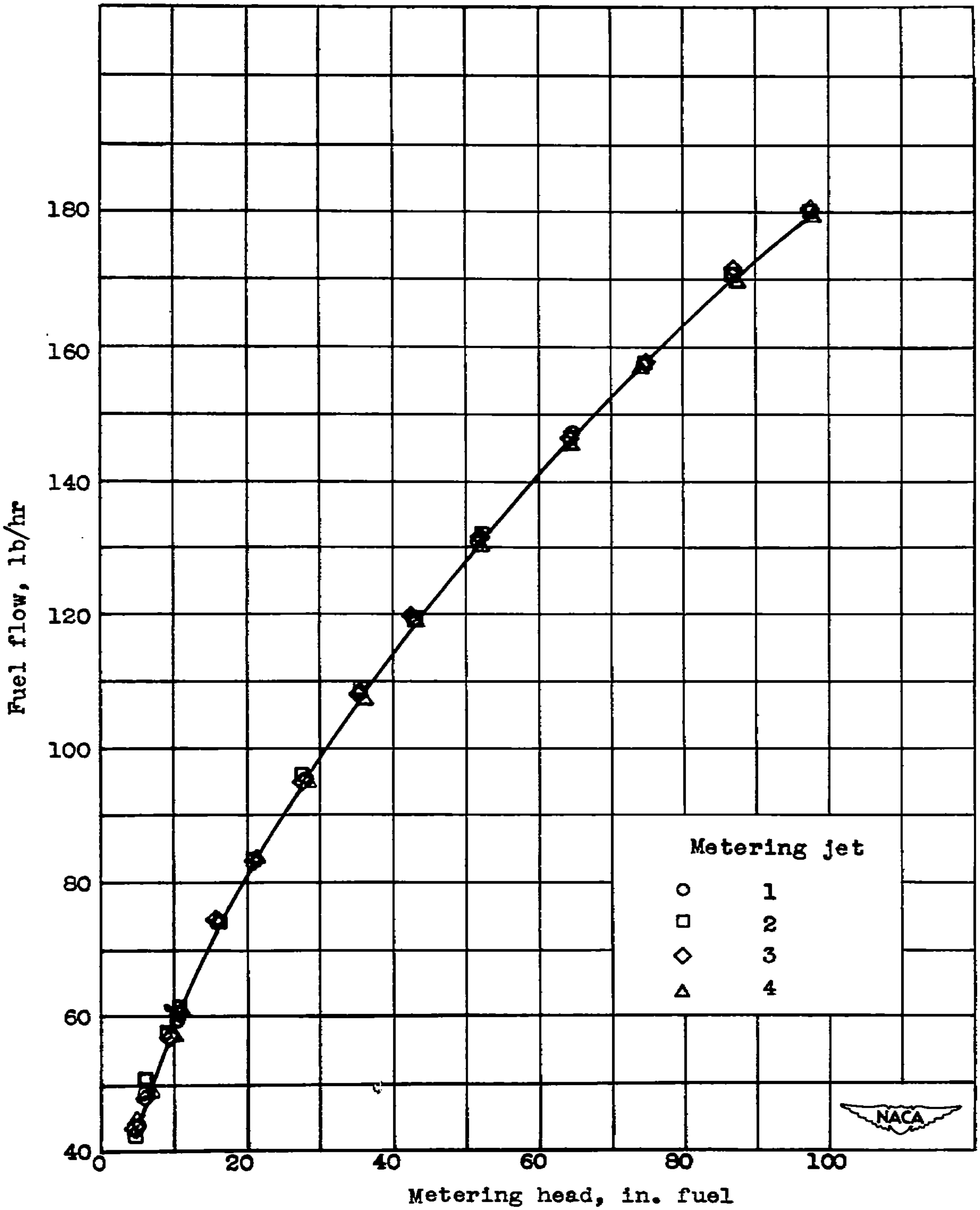

Figure 4. - Variation of fuel flow with metering head for matched metering jets used in experimental model of fuel-distribution control. Specific gravity of fuel, 0.74 at 70° F.

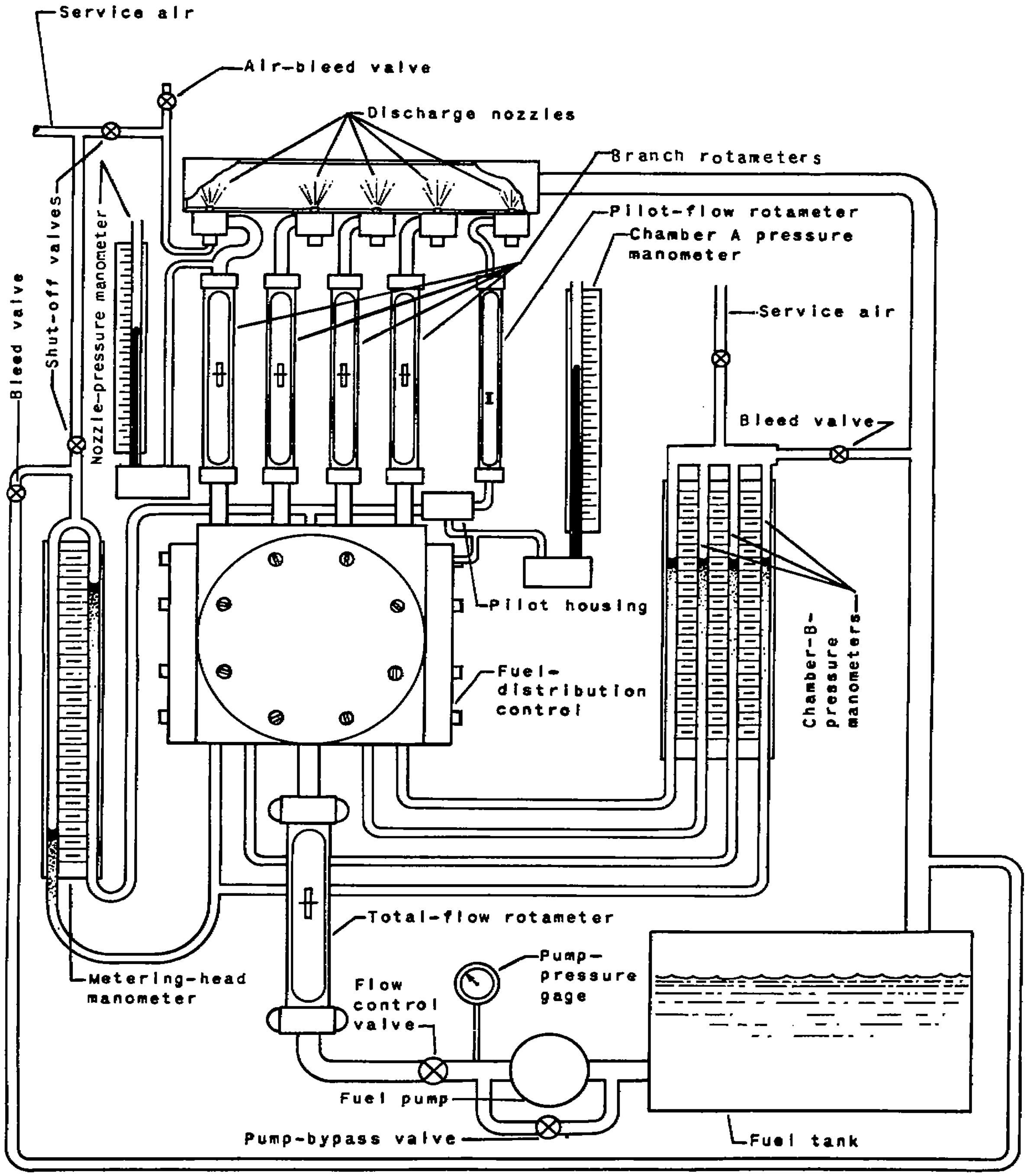

Figure 5. - Schematic diagram of apparatus used with experimental model of fuel-distribution control.

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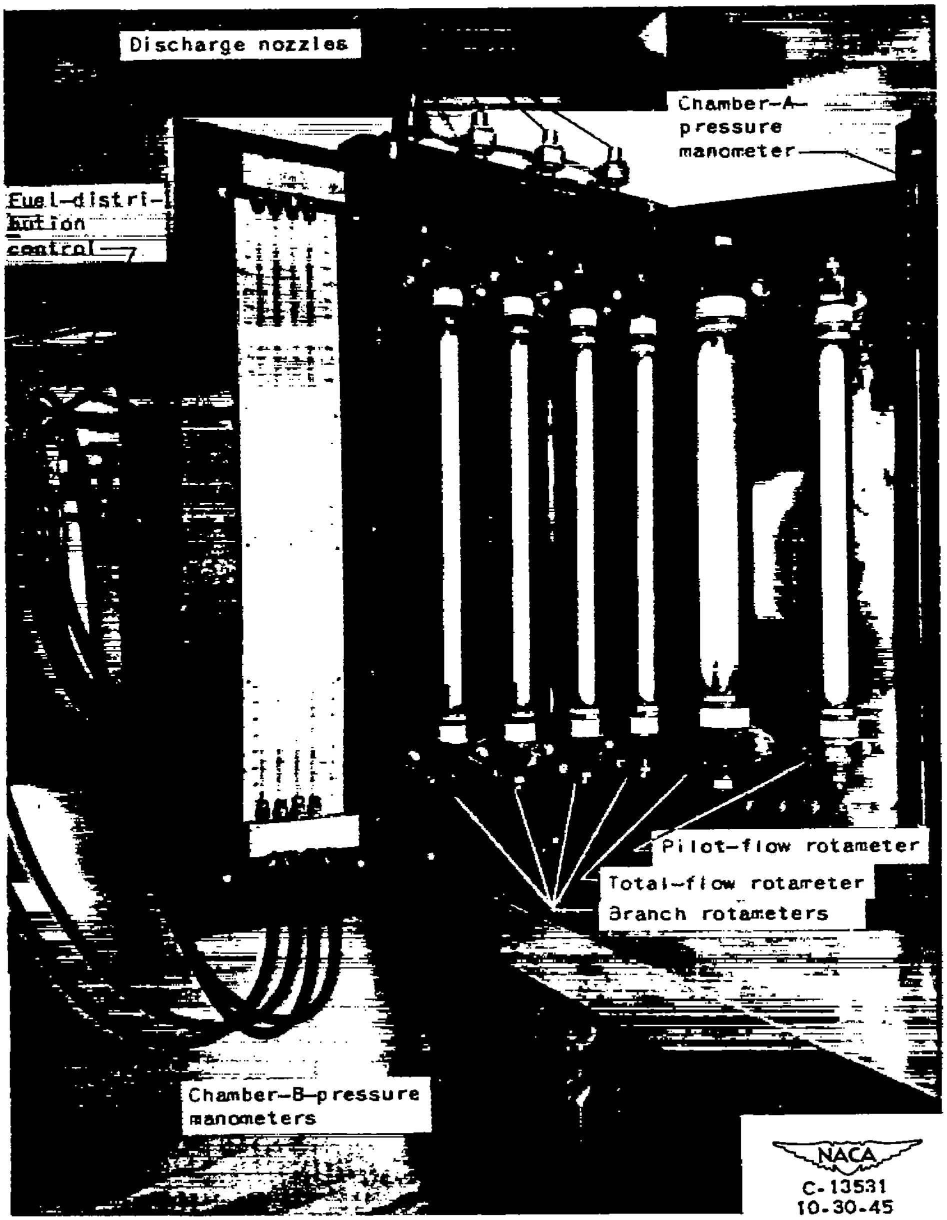

Figure 6. - Photograph of apparatus used with experimental model of fuel-distribution control.

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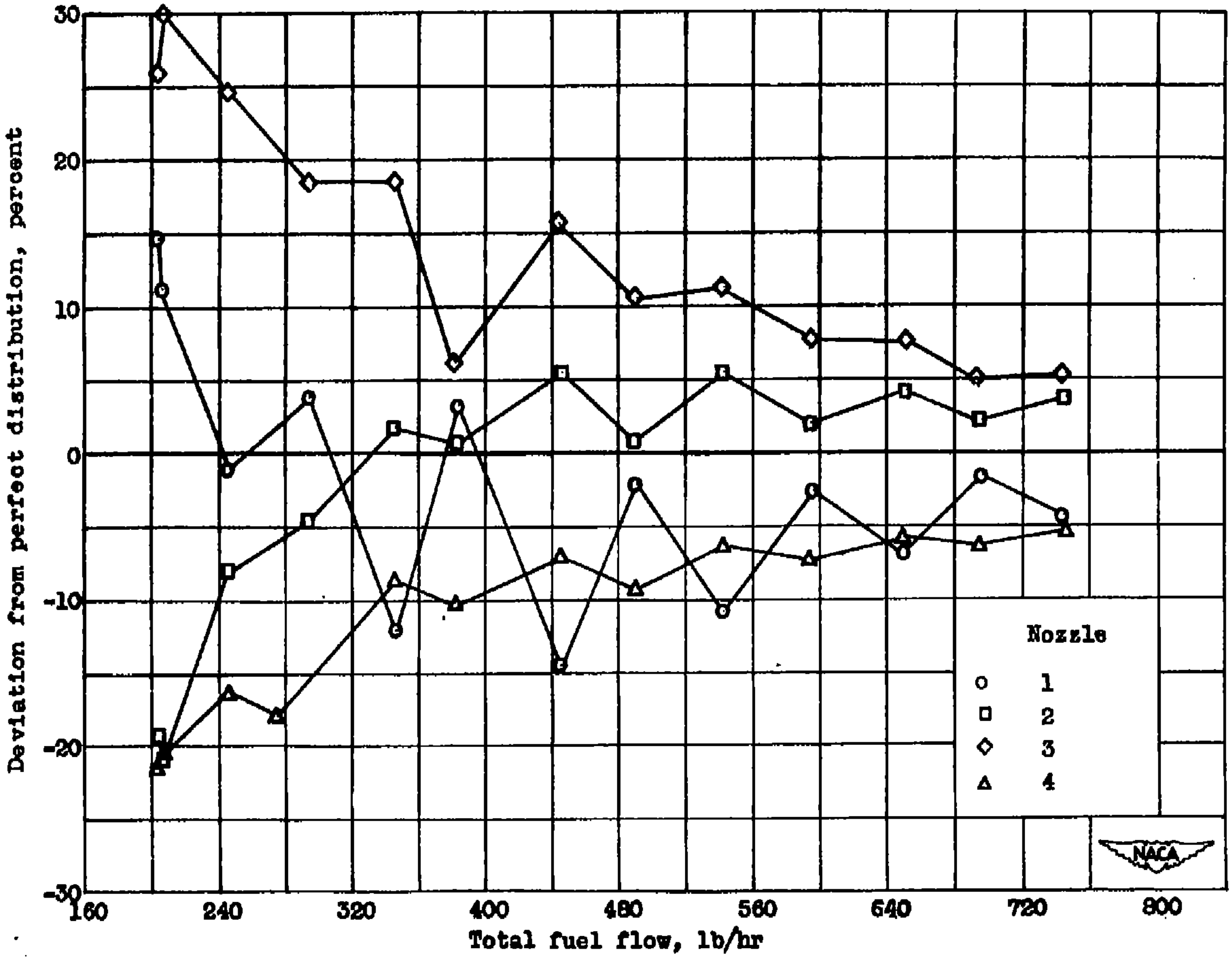

Figure 7. - Deviation from perfect distribution at various total fuel flows of spring-loaded nozzles connected to manifold.

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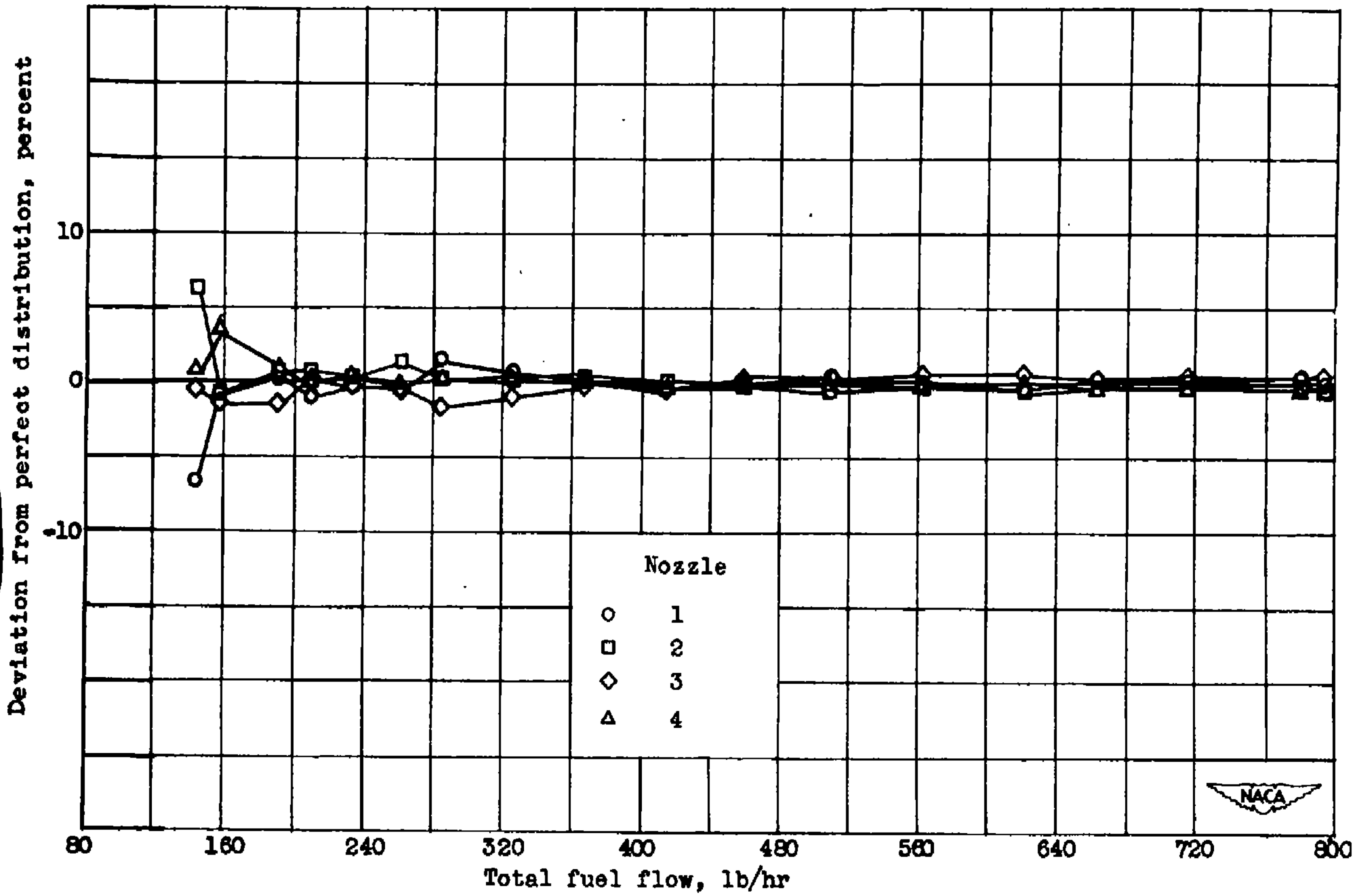

Figure 8. - Deviation from perfect distribution at various total fuel flows of spring-loaded nozzles connected to experimental model of fuel-distribution control for bench investigations.

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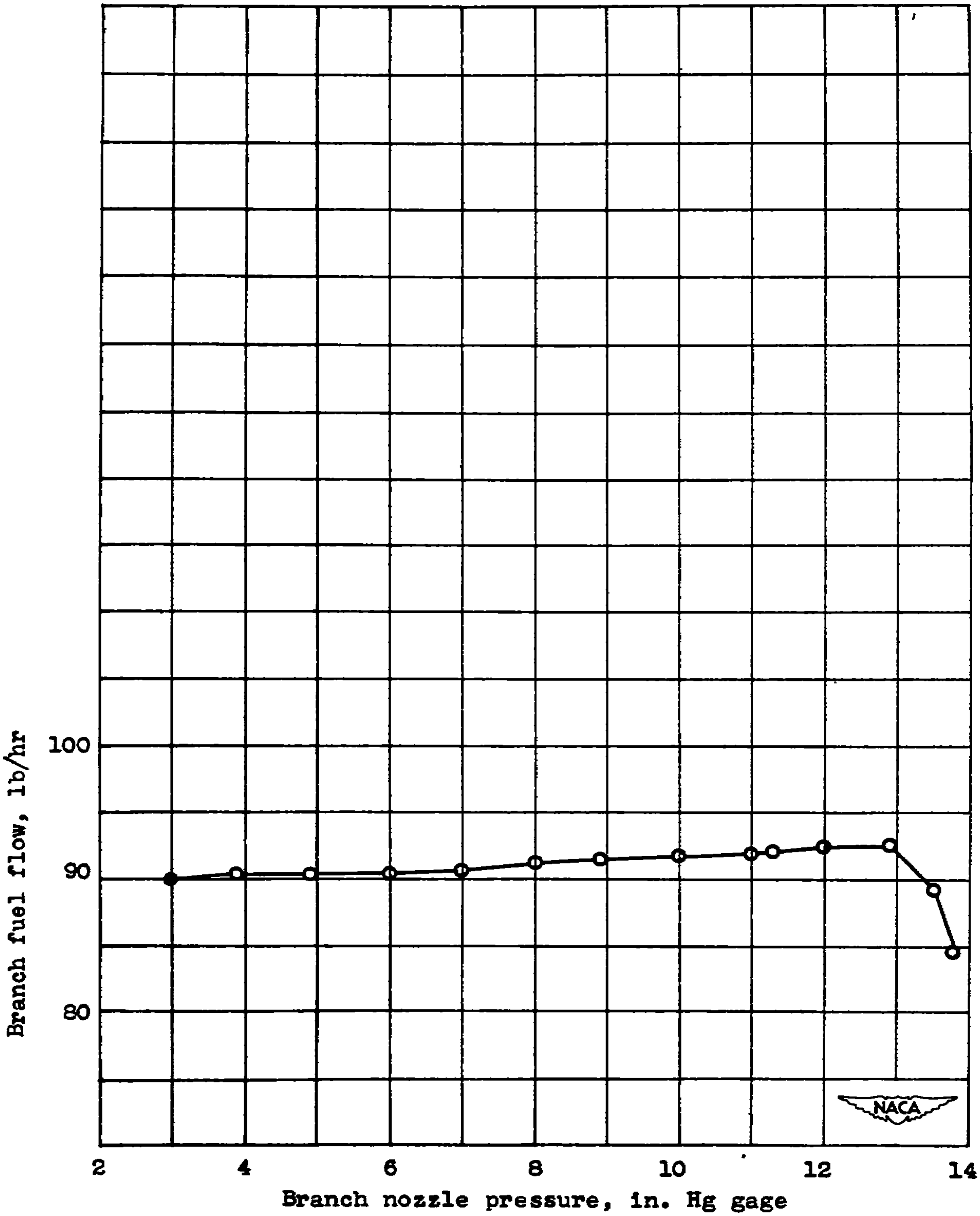

Figure 9. - Effect of varying nozzle-discharge pressure on branch fuel flow of experimental model of fuel-distribution control. Three discharge nozzles held at 11.3 inches of mercury gage; total fuel flow, 370 pounds per hour.

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